LONG TERM PERFORMANCE OF THREE BRIDGES ON PERMAFROST

FINAL REPORT

by

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16. Abstract

In 1964 the Alaska Department of Transportation and the U.S. Army Cold Regions Research and Engineering Laboratory initiated a cooperative study which in the long-term generated a significant amount of ground temperature and settlement data at three bridge sites near Fairbanks, Alaska. The purpose of the study was to evaluate the long-term bridge performance in order to improve bridge design techniques in areas where permafrost is present. Data over the past twenty (20) years has been reduced and evaluated revealing some drastic changes in the thermal regime. At the Goldstream Creek Bridge, settlements of approximately 6 in (15 cm) over a 10 year period were observed. At the Moose Creek Bridge, annual heave and subsidience with long term net uplifting has been measured. Differential settlements of more than 8 in (20 cm) and slight annual heaving have been measured at the Spinach Creek Bridge. This bridge analysis has demonstrated the hazards of relying on permafrost adfreeze bonding for support of piles located in streambeds in warm permafrost regions.

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TABLE OF CONTENTS

LIST OF FIGURES

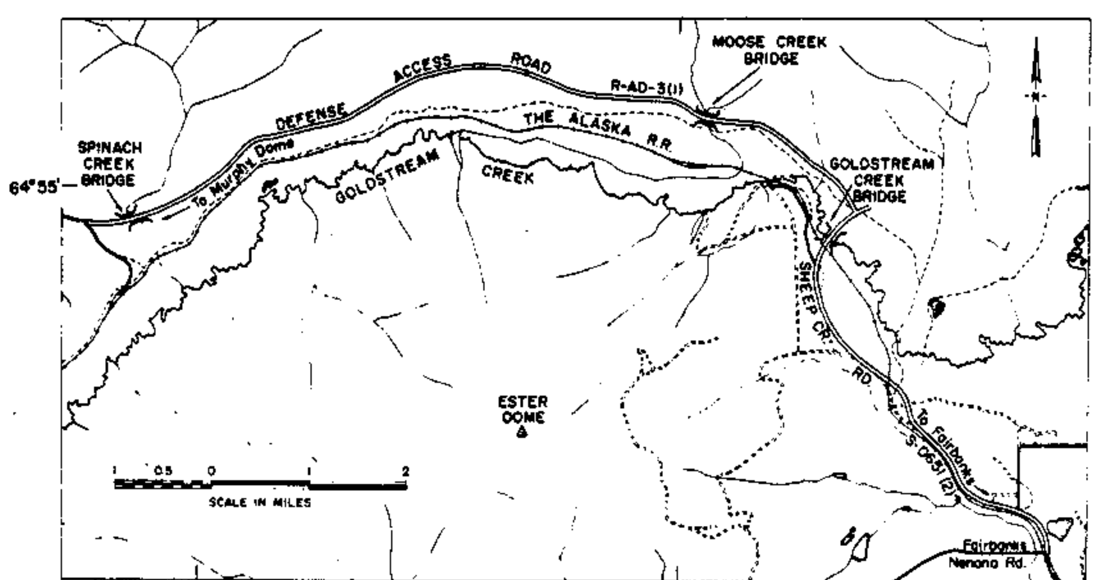
ABSTRACT

In 1964 the Alaska Department of Transportation and the U.S. Army Cold Regions Research and Engineering Laboratory initiated a cooperative study which in the long-term generated a significant amount of ground temperature and settlement data at three bridge sites near Fairbanks, Alaska. The purpose of the study was to evaluate the long-term bridge performance in order to improve bridge design techniques in areas where permafrost is present. Data over the past twenty (20) years has been reduced and evaluated revealing some drastic changes in the thermal regime. At the Goldstream Creek Bridge, settlements of approximately 6 in (15 cm) over a 10 year period were observed. At the Moose Creek Bridge, annual heave and subsidience with long term net uplifting has been measured. Differential settlements of more than 8 in (20 cm) and slight annual heaving have been measured at the Spinach Creek Bridge. This bridge analysis has demonstrated the hazards of relying on permafrost adfreeze bonding for support of piles located in streambeds in warm permafrost regions.

INTRODUCTION

In 1965 the Goldstream, Moose and Spinach Creek Bridges were constructed through virtually undisturbed terrain. The Goldstream Creek Bridge is located approximately 6 mile (10 km) from the University of Alaska's Experimental Station on Sheep Creek Road. The Moose and Spinach Creek Bridges are on Murphy Dome Road which runs along the north side of the Goldstream Valley (Figure 1). Permafrost was known to exist at all three bridge sites, and the bridges foundation were designed accordingly. However, settlement problems due to thawing permafrost at pier 2 of the Goldstream Creek Bridge, have caused substantial settlement of a midstream pier creating an obvious dip in the bridge deck. The Moose Creek Bridge has shown considerable progressive heaving in the last ten years. This is probably due to the thawing permafrost and resulting loss of pile ad-freeze resistance to jacking. Vertical movements at the Spinach Creek Bridge show a wide range in differential movement with one pile settling as much as 8 in (20 cm). Unlike the Moose Creek Bridge, the Spinach Creek Bridge heaved very little due to the anti-heave, pile sleeves and oil-wax-soil mixture which was used during pile installation. This report provides a long-term extension of the bridge performances which were previously reported by Crory, 1975.

FIGURE I: LOCATION MAP



INSTRUMENTATION

Thermocouple assemblies were installed in sleeves attached to selected piles at each bridge site directly following pile installation. The assemblies were constructed from 18-gauge copper-constantan wires and protected by polyethylene tubing. The thermocouples were normally spaced at 12 in (30.5 cm) intervals to a depth of 12 ft (3.7 m) and at increased spacings to just above the pile shoe. The lead wires were connected to panel boxes and mounted to the guard rail on the bridge deck. Initially ground temperatures were read monthly with a portable millivolt potentiometer, using an ice-bath reference. However, in recent years, more consistent digital voltmeters have been used, and readings have been less frequent. During construction, vertical movement points were installed using large diameter round head bolts placed in all four corners of the Goldstream Creek Bridge Bridge and the single span Moose Creek and Spinach Creek bridge decks directly above the pile caps. Additional points were established on the guard rail anchor bolts and each abutment wing wall of the Goldstream Creek Bridge so that the vertical movement of all three bridge spans and the vertical displacement or rotation of the wing walls could be observed.

SUMMARY OF SITE CONDITIONS

The climate at the bridge sites can be considered typical of Interior Alaska, having a continental climate characterized by an extreme range between summer and winter temperatures. The mean annual temperature reported for the Fairbanks International Airport is 25.7°F (-3.5°C) with extremes of +97°F (36°C) and -67°F (-55°C), and freezing and thawing indices averaging -3000 and +1850°C-days. Precipitation averages 11.8 in (30 cm) including the water equivalent of 5 ft (1.5 m) of snowfall.

The Goldstream Creek Bridge is located in a broad, shallow section of the Goldstream valley. At the bridge site, the Goldstream Creek is a widely meandering stream with steep banks and a well defined channel. The Alaska Department of Transportation Road Materials Laboratory conducted soil explorations for the three bridge foundations in mid-June of 1963. Based on the results of the borings, the soils at the Goldstream Creek Bridge site were described by Crory, 1968, as follows: "Silt with organic matter from the original ground elevations 551 to 553 ft" (168 to 169 m) "to an elevation of 535 ft" (163 m); "and fine to silty sand, with organic matter and local layers of gravelly sand to the maximum depth of the exploration (elevation 485 and 488 ft)" (elevation 148 and 149 m).

Moose Creek and Spinach Creek Bridge sites are similar in geology and vegetation. Both provide major drainage from the hills to the north and are underlain by Birch Creek shist which exhibits various degrees of weathering with depth. Soils consist of approximately 10 ft (3 m) of silt and organic silt which is derived from the surrounding loess covered slopes. The vegetation cover adjacent to these streams is typically short black spruce, with alders, willows, and sphagnum mosses. Both streams experience high spring runoff, but the normal summer flows are very small. There has been no evidence of scouring at either stream before or after construction. No icing has been observed at the Spinach Creek Bridge, however, icing overflows extending out from the Moose Creek channel and measuring 6.6 ft (2 m) in thickness have been observed.

Based on the results of the soil borings, the soils at the Moose Creek site were described by Crory, 1975, as follows: "Organic silts from the original ground elevations (570-572 ft)" (174 m) " to an elevation of about 555 ft;" (169 m) "silty gravelly sand to silty sandy gravel to an elevation of about 535 ft;" (163 m) "and weathered micaceous schist bedrock from that elevation to the maximum depth of exploration (50 ft)' (15 m).

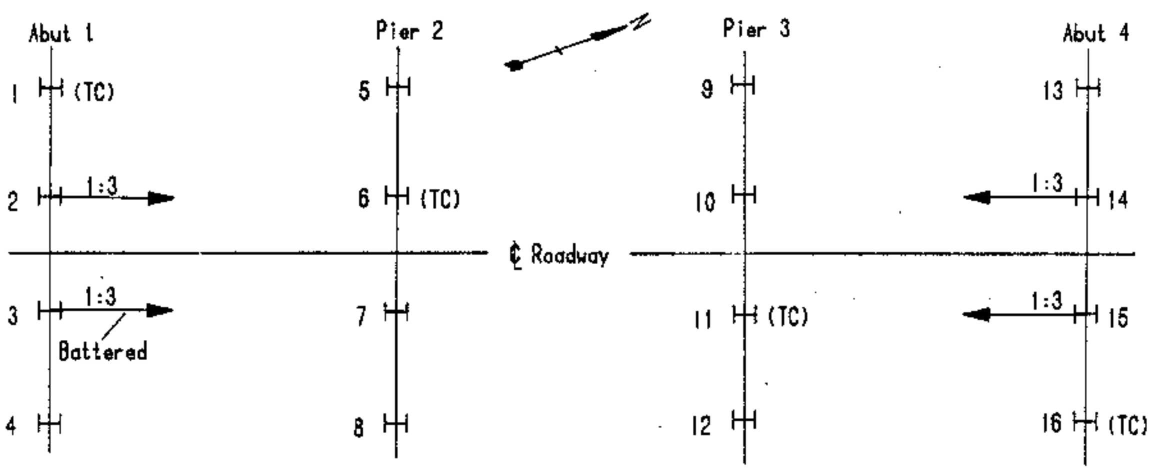
The soil explorations at the Spinach Creek Bridge site showed an organic silt layer approximately 30 ft (9 m) thick underlain by a zone of severely weathered schist. According to Crory, 1975: "The weathered schist zone takes the form of silty sand and gravel and was found to be permanently frozen."

GOLDSTREAM CREEK BRIDGE

Pile driving began at the Goldstream Creek Bridge in May of 1965. Each abutment and pier is supported by four 10 BP 57 piles at locations as shown by Figure 2. The two interior piles in each abutment were battered towards the stream (1H:3V) in order to counter the thrust of the abutment fill. All abutment piles were driven to an elevation of 520 ft (158.5 m) [approximately 42 ft (12.8 m) below the approach fill]. The two piers, each consisting of four vertically installed piles were driven to an elevation of 510 ft (155.4 m), [approximately 35 ft (10.7 m) below the streambed]. Due to the relative ease with which the piles in Pier 2 could be driven, pile 9 was driven an additional 8 ft (2.5 m) to an elevation of 502 ft (152.9 m).

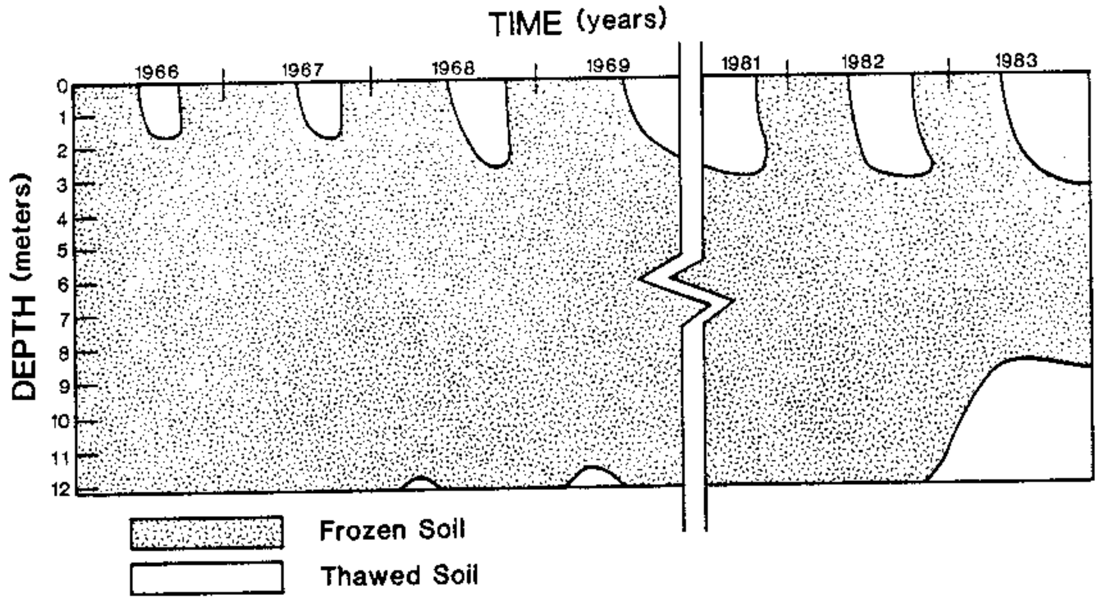
For more detailed information on initial site selection, soil borings, design, specifications, pile driving and construction see Crory, 1968.

FIGURE 2: GOLDSTREAM CREEK PILE LOCATIONS (TC DENOTES THERMOCOUPLE LOCATION)



The changes in frozen and thawed zones,as determined from periodic temperature readings along one of the piles supporting Abutment 1 show a degenerative permafrost condition over the past seventeen years (Figure 3). This condition was first noted by Crory in 1968. "The temperature in the middle and bottom sections of the pile length in permafrost is only about 31.2°F" (-0.44°C). "In addition to the warm permafrost temperature, the negative gradient (decreasing temperature with increasing depth below about 10 ft" (3m) "suggests a degenerative or warming permafrost trend." At the time of construction, Pile 1 of Abutment 1 was imbedded in approximately 33 ft (10 m) of permafrost. Presently only about 16 ft (5 m) of the pile is in permafrost.

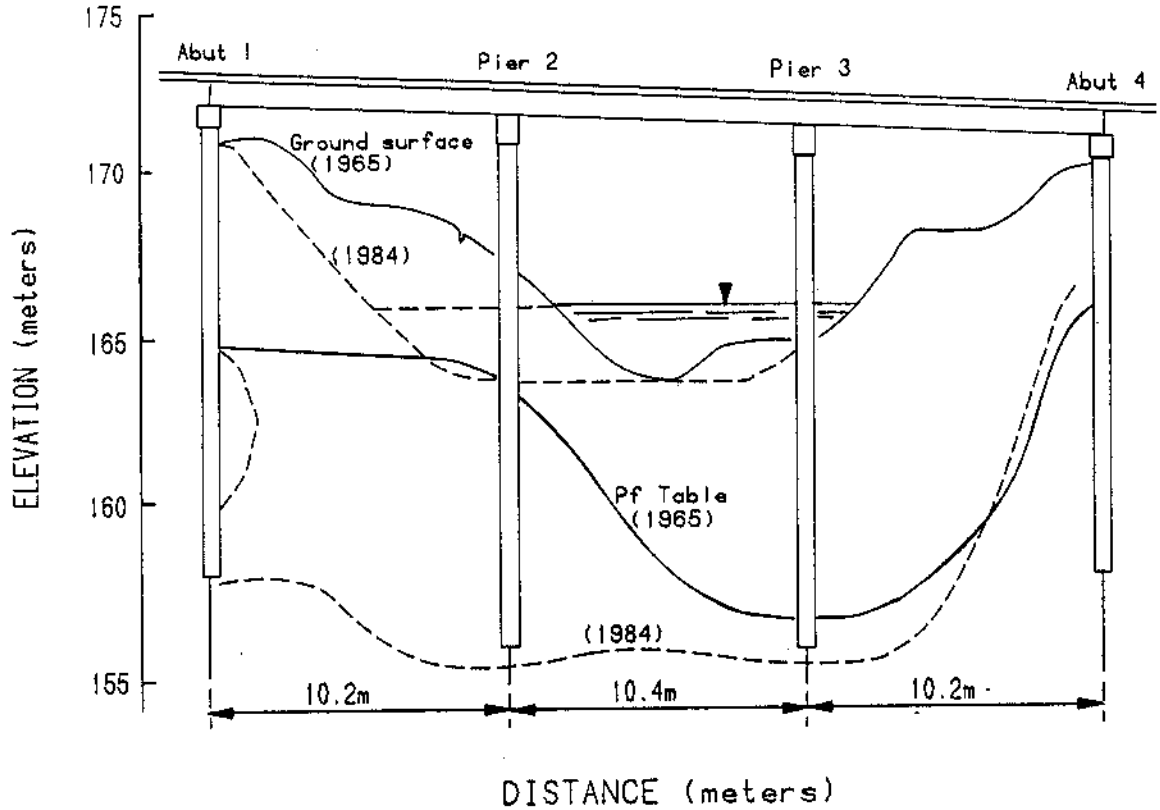
FIGURE 3: DEGRADATION OF PERMAFROST OVER TIME AT PILE 1, ABUTMENT 1 OF THE GOLDSTREAM CREEK BRIDGE



The permafrost table has been affected by warming from the southward shifting stream bed, cooling from the absence of snow under the bridge which facilitates deep frost penetration at the abutments, and warming from heat flow from ground water flow in the thaw bulb. It would have been very difficult to anticipate the current permafrost conditions and changes from those of 20 years ago when the bridge was designed and built.

Pier 2 has experienced the most dramatic change in the depth to permafrost, with the permafrost table falling to below the pile tips (see Figure 4). The south side stream bank which was originally penetrated by Pier 2, has eroded badly with much of the erosion taking place during the 1967 flood. At present, the stream bed has widened to the south by approximately 16 ft (5 m) from it's location in 1965, causing the increased size of the thaw bulb beneath the stream. Progressive settlements as much as 1.2 in (3 cm) per year have occurred at Pier 2, in addition to minor frost heaving each winter. After settlements amounting to more than 6 in (15 cm) had occurred by 1974, creating an obvious dip in the bridge deck, repairs were made by raising and shimming the main girders. The large settlements occurring at Pier 2 are the result of losses of support and down-drag due to the thawing and consolidating permafrost around the piles.

FIGURE 4: CROSS-SECTION OF GOLDSTREAM CREEK BRIDGE SHOWING CHANGE IN PERMAFROST CONDITIONS



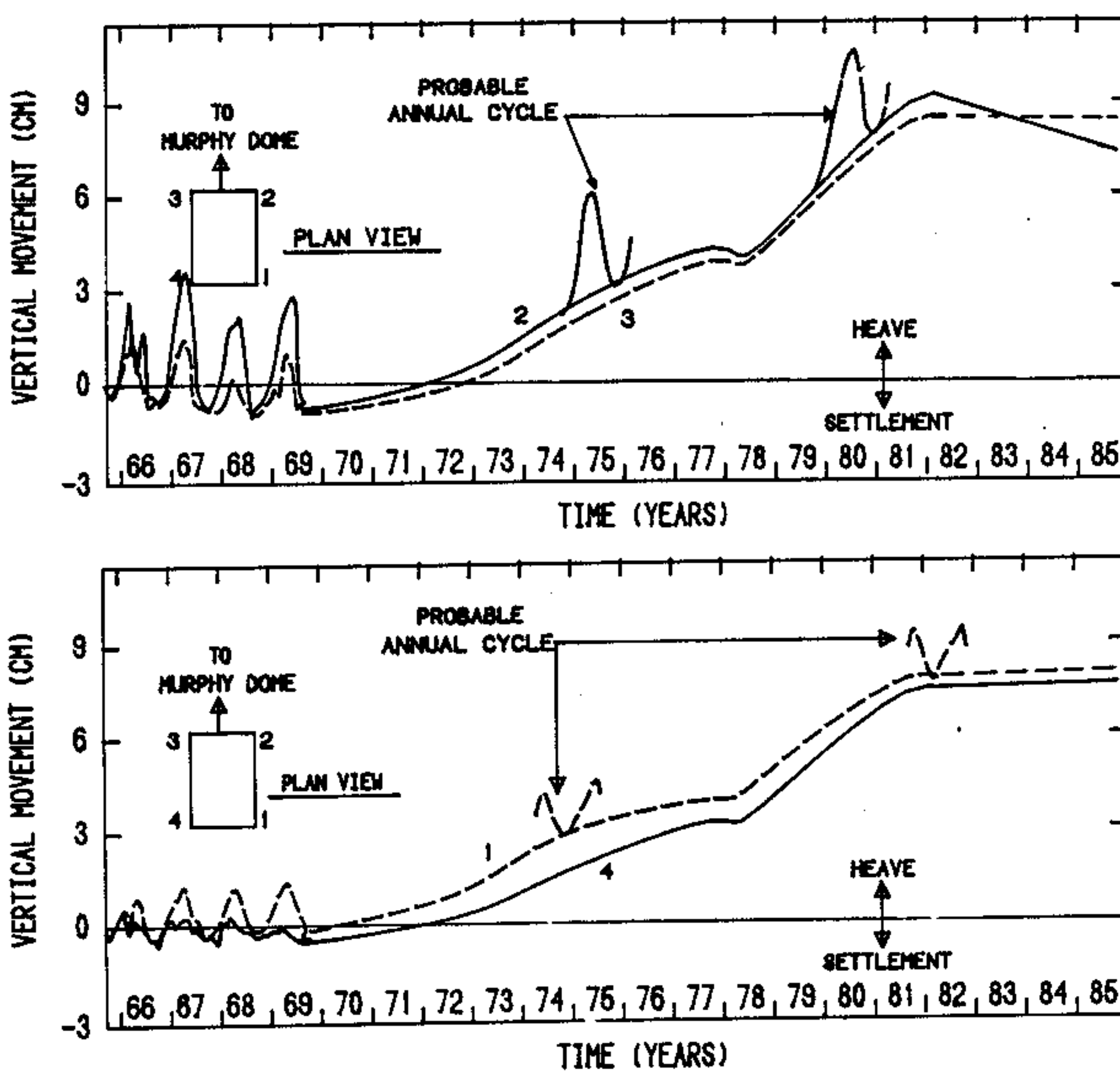
The present permafrost condition at Pier 3 is very similar to Pier 2. Ground temperature data and probe surveys both indicate that the permafrost table progressively dropped from approximately 3 ft (1 m) above the pile tip to just below the pile tip. Pier 3 performed comparatively better than Pier 2 due to the fact that Pier 3 was driven in already-thawed soils. Piles 9, 10, 11, and 12 of Pier 3 penetrated the first 18 ft (5.5 m) of soil with relative ease with pile 2 plunging 18 ft (5.5 m) under the weight of the hammer and pile only. Pile driving records indicate very little resistance was encountered until the last 4 ft (1.2 m) of pile driving.

The depth to permafrost at Abutment 4 appears to have remained relatively stable. The absence of snow around the abutment, the shading effect of the bridge deck, and the regrowth of vegetation on the south sloping stream bank appear to have been beneficial in retaining the permafrost conditions. Vertical movement data at Abutment 4 are very similar to that of Abutment 1 with approximately 0.8 in (2 cm) of settlement in the first two years and the remaining settlements of 0.2 in (0.5 cm) per year being attributed to creep due to the relatively warm permafrost at this site.

MOOSE CREEK BRIDGE

Pile driving for the Moose Creek Bridge started 13 May, 1965. The Moose Creek Bridge is a single span bridge 49 ft (14.8 m) in length. The bridge piles are approximately 27 ft (8.2 m) long, driven into a sand and gravel stratum to the specified design tip elevation of 543 ft (165.5 m). Bedrock at the Moose Creek site was encountered at an elevation of approximately 533 ft (162.4 m). However, bearing in the sands and gravel was considered sufficient and there was thought to be adequate imbedment in permafrost to prevent frost heaving. The long-term elevation data shown in Figure 5 indicate a progressive annual heaving of the entire bridge deck

FIGURE 5: DISPLACEMENT WITH TIME MOOSE CREEK BRIDGE

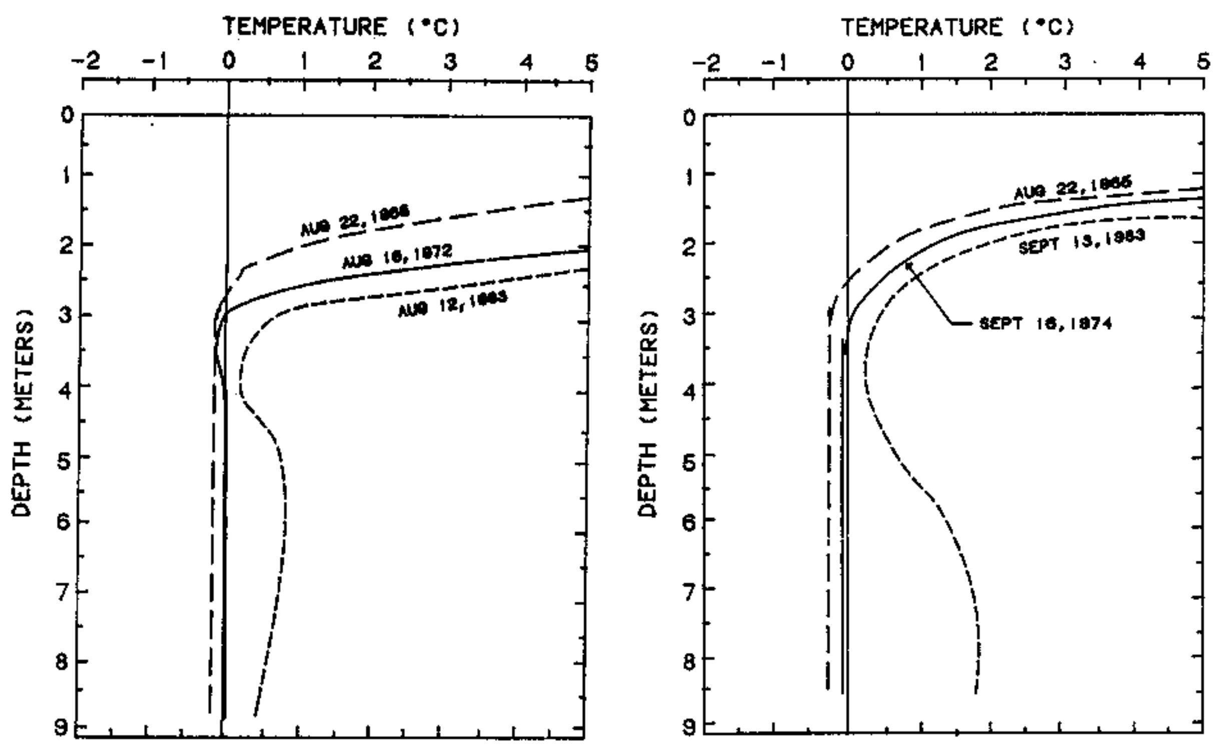


beginning in the early 1970's. It is apparent from the temperature data shown in Figure 6 that the loss of ad-freeze strength due to the thawing permafrost in the early 70's is responsible for the bridge heaving as much as 5 in (12 cm). The temperature data also indicate there was a small amount of thawing taking place from the surface and the majority of the thawing was due to lateral heat flow from ground water which expanded the thaw bulb beneath the stream. Beginning in the early 80's to the present, heaving of the bridge appears to have stopped with only a slight upward movement in the past four years. A possible explanation for the present stability of the bridge may be attributed to the eventual consolidation of the soil near the pile after thawing.

FIGURE 6: GROUND TEMPERATURES AT MOOSE CREEK BRIDGE

Abutment #2, Pile #5

Abutment #1, Pile #4

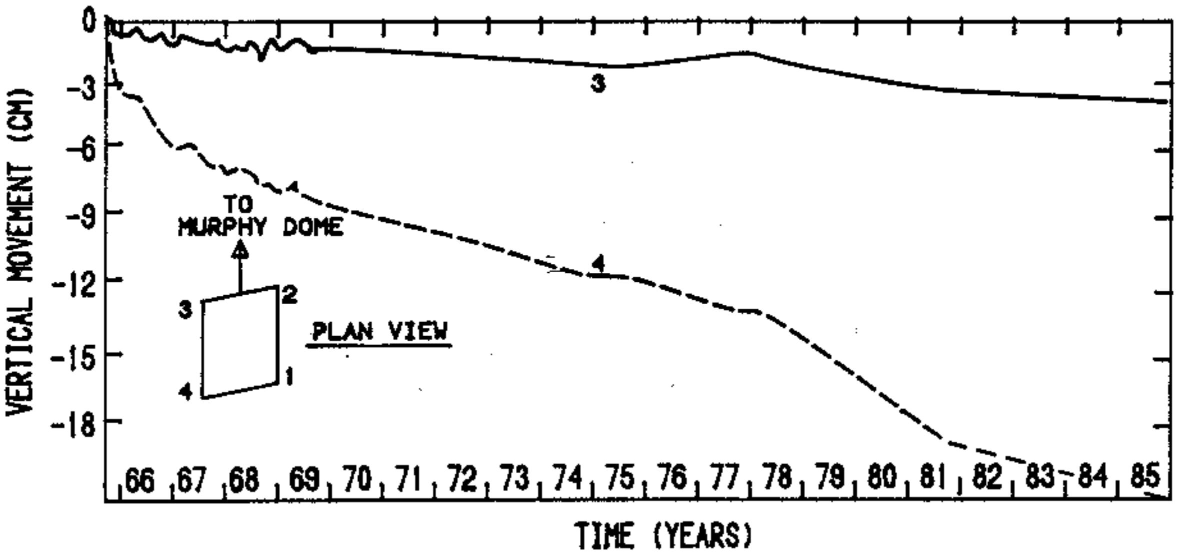


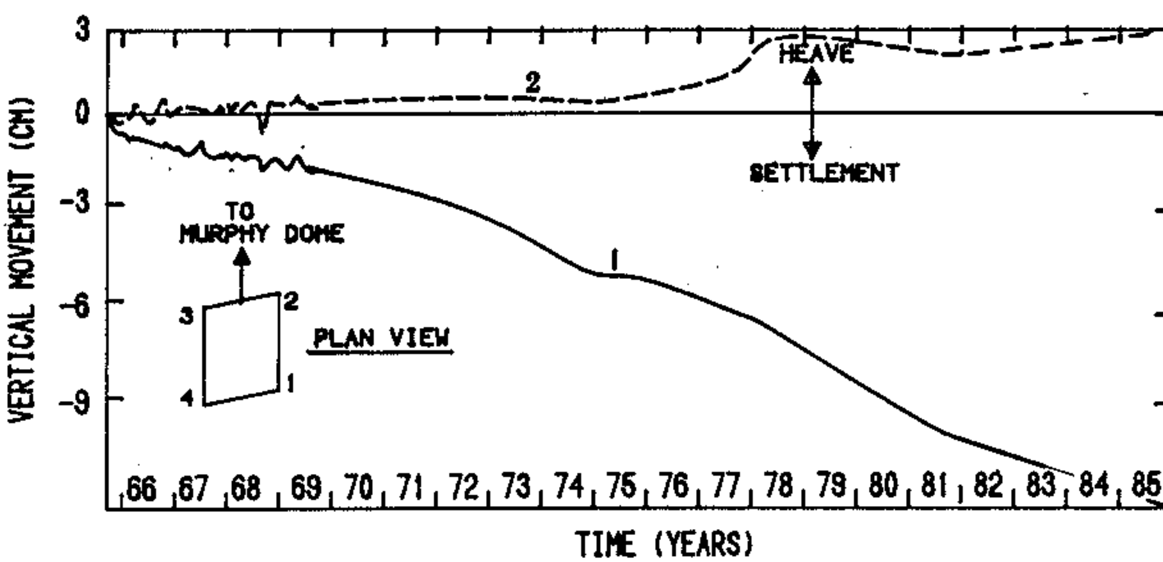
Stream overflow icing at the Moose Creek Bridge has at times been severe, measuring 6.6 ft (2 m) thick and extending beyond the stream channel. At times the ice on the upstream side of the bridge has reached the level of the bridge deck. The situation is sometimes alleviated by steam thawing a channel in the ice during spring to allow water to flow without serious erosion to the stream banks. The icing problem appears to have been corrected by constructing a dike on the upstream side of the bridge and by removing the organic streambed material and backfilling with rock in order to enhance the streambed flow rate. Of the three bridges studies, Moose Creek has been the only bridge which has been plagued by icing problems.

SPINACH CREEK BRIDGE

Pile driving for the Spinach Creek Bridge began on 25 March, 1965. The bridge is a single span 61 ft (18.5 m) long bridge skewed 60° to the centerline, allowing for the angle at which the stream confronts the road. The bridge foundation consists of eight 10 BP57 piles, all driven to a specified design tip elevation of 484.5 ft (147.6 m), with the exception of pile eight, which was driven to an elevation of 482 ft (146.8 m) in order to obtain the specified minimum bearing value of 45 tons as calculated by the Modified Engineering News Formula. There was no attempt to drive the piles to refusal even though bedrock was approximately at an elevation of 480 ft (146.3 m). Because of the shallow depth to which the piles were driven, frost heaving was a major design concern. For frost heave protection, piles were set in pre-augered 10 ft (3 m) deep holes, then cased and later filled with an oil-wax-soil mixture. Vertical movement data at the Spinach Creek Bridge indicate a wide range in motion (see Figure 7), with the bridge deck becoming diagonally warped as much as 9.5 in (24 cm). Abutment 1 (VM 1, and VM 4) has settled considerably in the past 20 years indicating the need to have driven the piles to bedrock which may be just a few inches below the pile tips. A marked increase in the rate of settlement

FIGURE 7: DISPLACEMENT WITH THE SPINACH CREEK BRIDGE



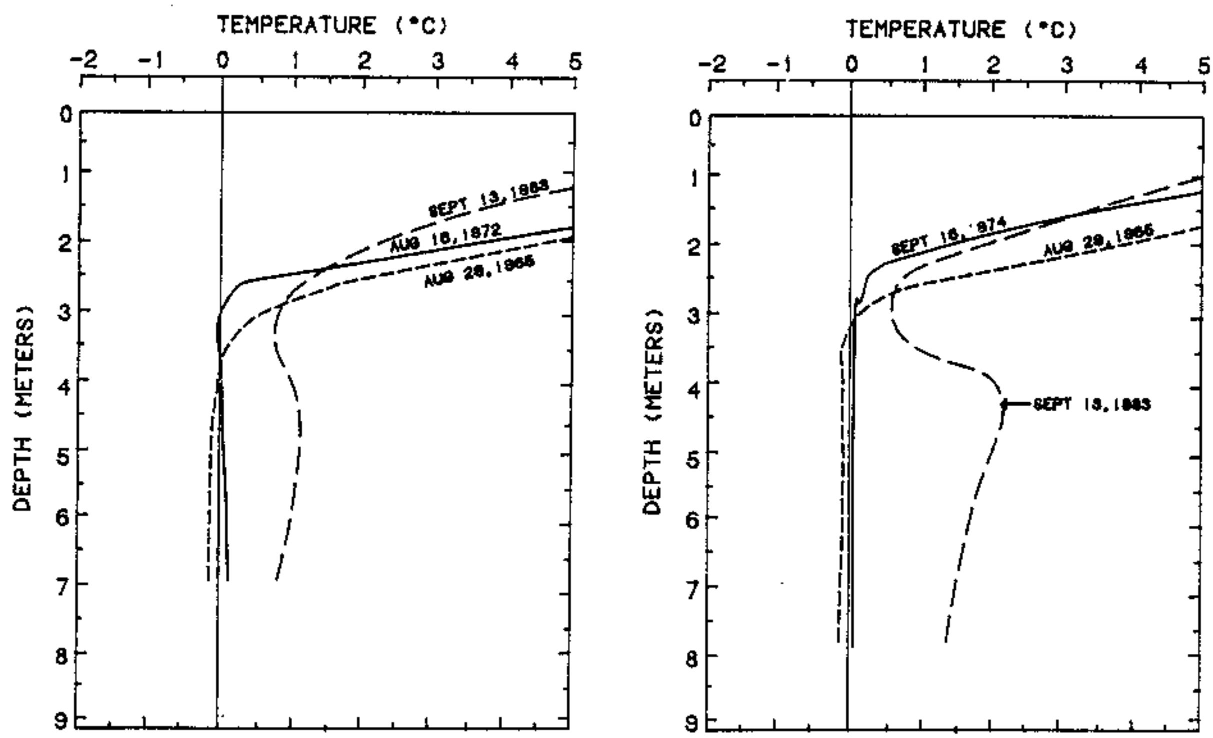


in the late 70's to the early 80's may be an indication of when the permafrost had completely thawed near the piles. As shown by Figure 8, the permafrost surrounding both instrumented abutment piles has progressively thawed entirely during the past 20 years. Unlike the Moose Creek Bridge, there is little evidence of frost heaving at Spinach Creek. Vertical movement point 2 is the only VM point which did not settle. This may be because VM 2 is located directly over the one pile driven to an elevation of 482 ft (146.8 m). There was also a marked increase in heave rate in the late 70's indicating the thawing of the permafrost and loss of heave resistance during that time period.

Moose Creek Bridge, with very similar soil conditions to those at Spinach Creek, heaved considerably indicating the anti-heave pile sleeving technique to be very effective in reducing or eliminating frost heave.

FIGURE 8: GROUND TEMPERATURES SPINACH CREEK BRIDGE

Abutment #1, Pile #1 Abutment #2, Pile #8



CONCLUSIONS AND IMPLEMENTATION ACTIONS

This study has provided a unique opportunity to observe the long-term changes in vertical movement as they relate to changes in ground temperature. It is evident from the drastic changes in the thaw bulbs, due to the shift in the stream channel at the Goldstream Creek Bridge and to progressive permafrost thawing at all sites, that designers must give careful attention to the thermal regime of streams in permafrost areas, both before and after construction. The progressive settlements and frost heaving observed at Moose and Spinach Creek Bridges raises serious concern about the adequacy of any pile foundation being designed on the basis of permafrost ad-freeze strength. The piles at all three bridge sites appear to have been affected to some degree by a change in the permafrost condition. Designing bridge piles for an ultimately thawed condition appears logical and necessary in retrospect. However, the effects of negative down-drag that thawing and consolidating permafrost exerts on piles must be carefully considered even when designing for thawed condition. The settlement at Spinach Creek and the different performance of Piers 2 and 3 at the Goldstream Creek Bridge demonstrates the effect of down-drag on a pile driven into permafrost and then thawed, as compared to a pile driven into already thawed soil The heaving at Moose Creek shows the potential results of relying on the permafrost ad-freeze with shallow piles whereas Spinach Creek focuses attention on the benefits of antiheave treatments.

ACKNOWLEDGEMENTS

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REFERENCES

Crory, F.E., 1975. Bridge Foundations in Permafrost Areas, Moose and Spinach Creeks, Fairbanks, Alaska, Technical Report 266, Hanover, NH, U.S. Cold Regions Research and Engineering Laboratory.

Crory, F.E., 1967. Pile Foundations in Discontinuous Permafrost Areas, Special Report 79, Hanover, NH, U.S. Cold Regions Research and Engineering Laboratory.

Crory, F.E., 1968. Bridge Foundations in Permafrost Areas, Goldstream Creek, Fairbanks, Alaska, Technical Report 180, Hanover, NH, U.S. Cold Regions Research and Engineering Laboratory.

Crory, F.E. Long-Term Foundation Studies of Three Bridges in the Fairbanks Area, Technical Report (in preparation), Hanover, NH, U.S. Army Cold Regions Research and Engineering Laboratory.

Pe´we´, T. and Paige, R., 1963. Frost Heaving of Piles with an Example from Fairbanks, Alaska, U.S. Geological Survey, Bulletin 111-1.